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NIC

National Ignition Campaign (NIC) Hohlraums
Part 1: Symmetry & Coupling

Presentation to
NIC Science of Ignition Webinar Tutorial Series
May 10, 2012 LLNL, Livermore, Ca

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NNSA GENERAL ATOMICS UR LLE Lawrence Livermore National Laboratory Los Alamos NATIONAL LABORATORY Sandia National Laboratories

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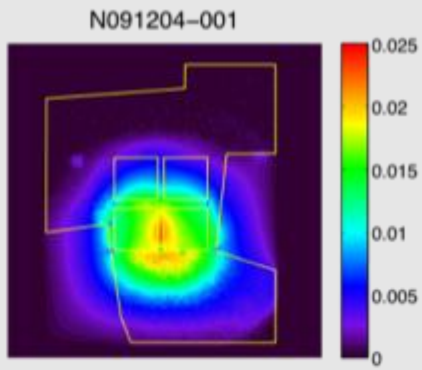
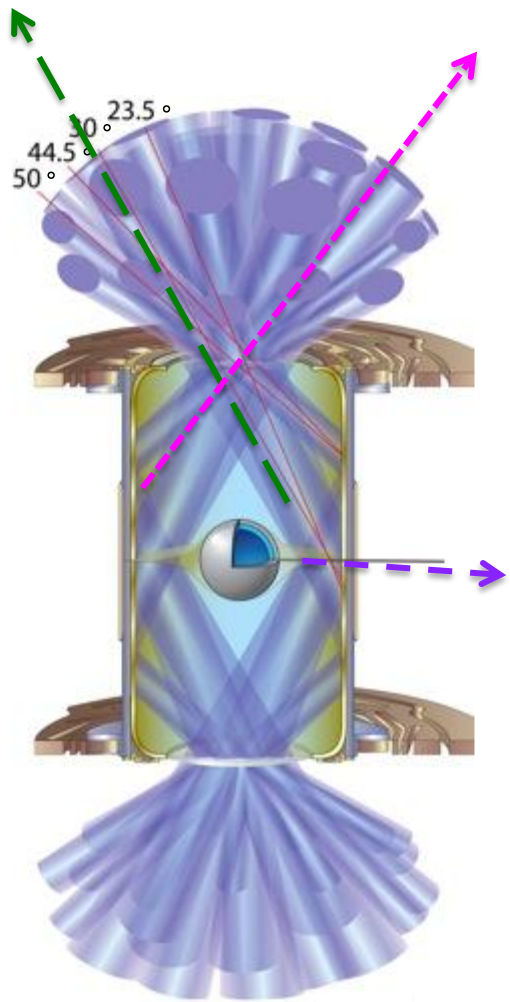
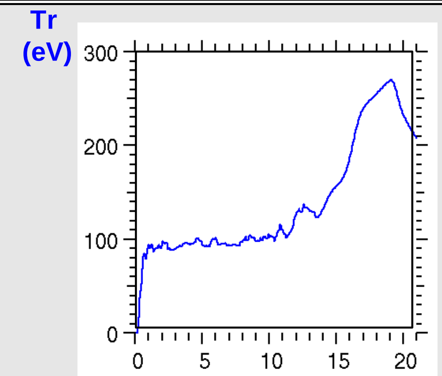
An ignition-scale hohlraum must provide good Coupling, Drive, & Symmetry

Coupling: LPI must be low enough, so that enough energy is available for drive

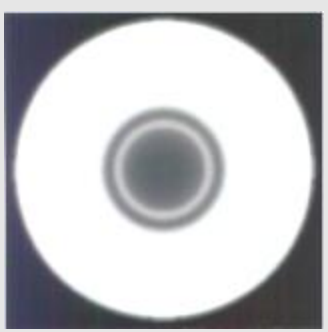




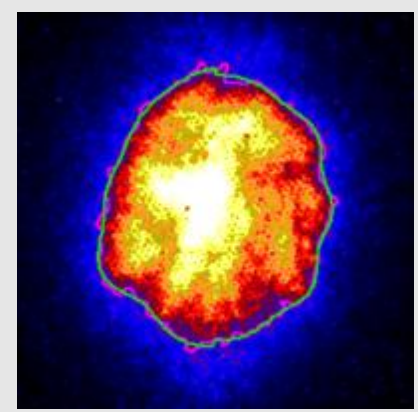
Drive: Must be high enough to implode a stable shell fast enough to get hot & ignite



Coupling: LPI must be low enough, so hot electrons do not pre-heat the target



Symmetry: Must be round enough at high convergence to get dense & ignite



In this talk we discuss basic issues / trade-offs in ignition-scale hohlraum design

Part 1: Symmetry & Coupling

Part 2: Ignition-scale-specific issues …
…and the emergence of the high flux model*

*M. D. Rosen, H. Scott, D. Hinkel et al HEDP 7, 180-190 (2011)

D. Hinkel, M. D. Rosen, E. Williams, et al PoP 18, 056312 (2011)

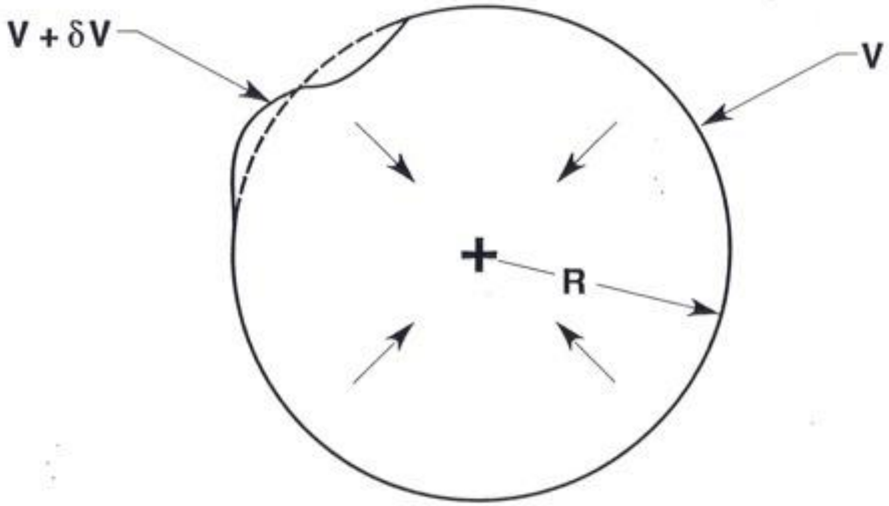
R. Town, M. D. Rosen, P. Michel et al PoP 18, 056302 (2011)

Hohlraums vs. (Polar) Direct Drive

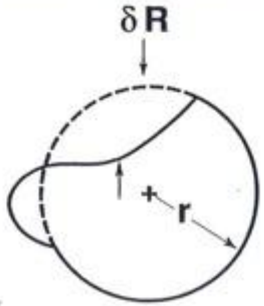
- **Advantages:**
-
  - **1) Geometric smoothing of short λ drive asymmetries**
  - **2) X-ray drive can have higher capsule implosion "rocket efficiency"**
  - **3) X-rays do better at ablation stabilization of the Rayleigh-Taylor instability**
- **Commonalities:**
  - **1) Need to control (via beam pointing) long λ drive asymmetry (e.g. P2, P4)**
  - **2) LPI challenging in long scale length plasmas**
- **Disadvantages:**
  - **1) Poorer capsule coupling efficiency (X-rays mostly in walls & out the LEH)**

Implosion symmetry is an important issue for high convergence ratio ("CR") targets

Small nonuniformity when outershell is at large radius



Becomes magnified when shell is imploded to a very small radius



$$\delta R = (\delta V)t \sim \delta V \frac{R}{V} < 1/2\ r$$

$$\therefore \frac{\delta R}{r} = \left(\frac{\delta V}{V}\right)\frac{R}{r} < 1/2$$

$$\therefore \frac{\delta V}{V} < 1/2 \frac{r}{R} < 1/2\ (\text{conv. ratio})^{-1}$$

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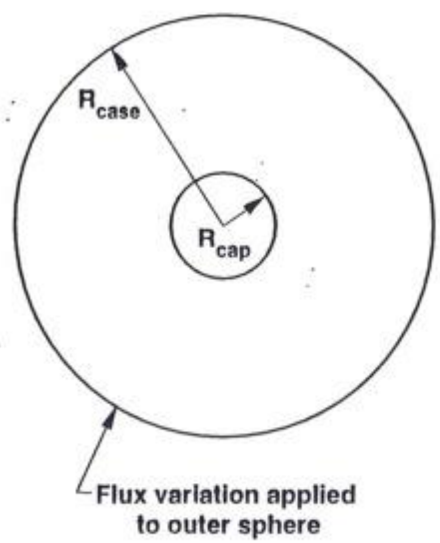
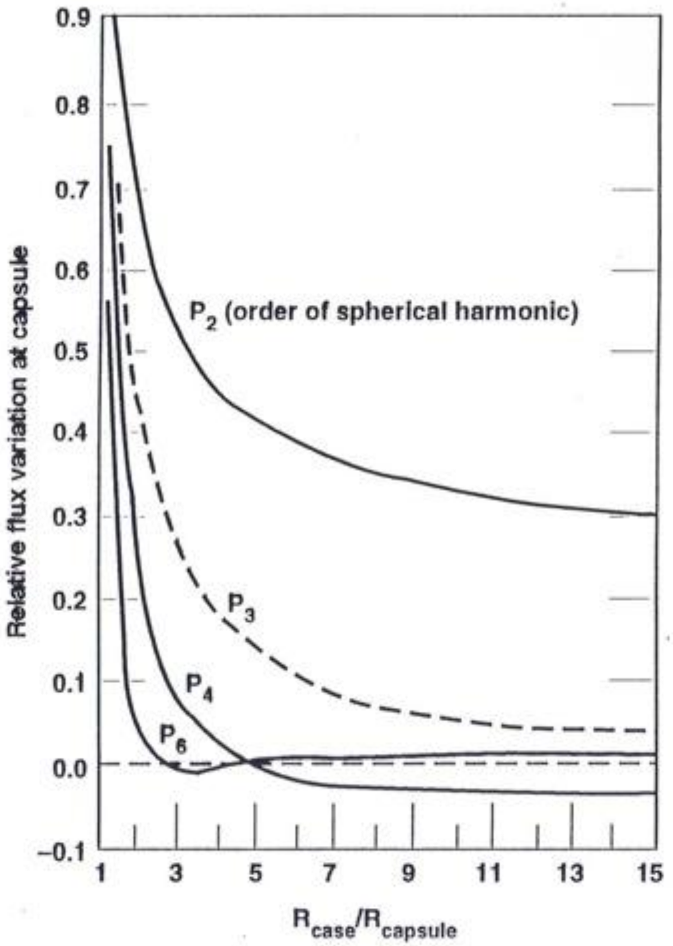
MDR/jco

CR =30 requires 1 to 2 % initial uniformity

Hohlraums smooth short λ asymmetry via geometry

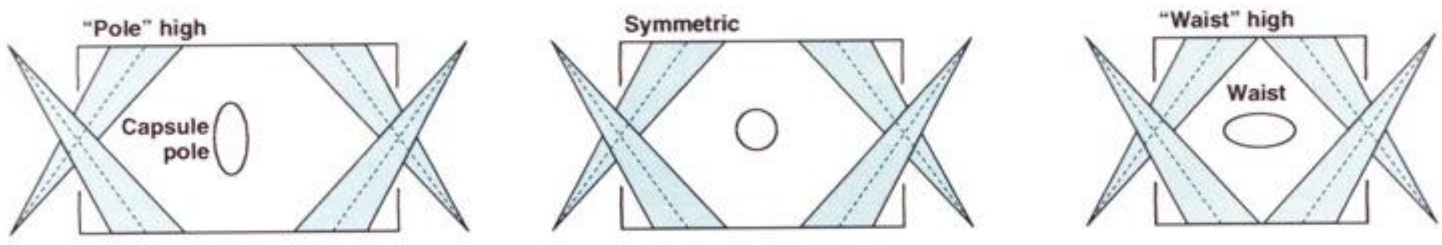


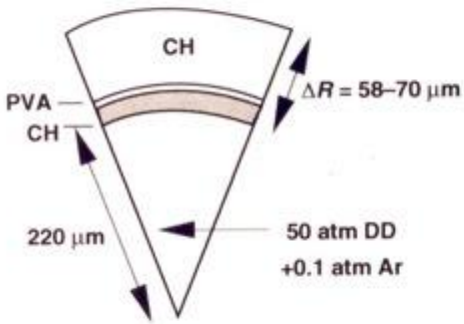


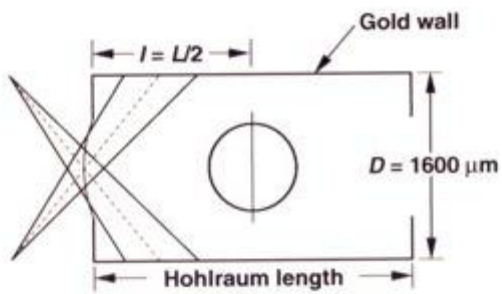
R_{case}/R_{cap} = 4 needed for good symmetry, but has energy coupling implications…

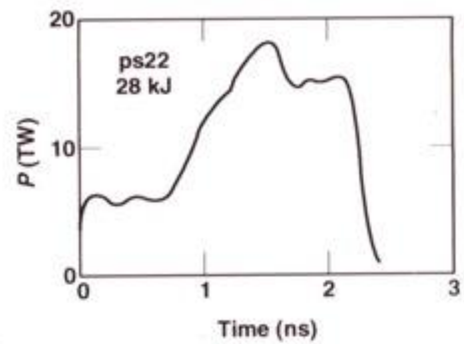
Hohlraums smooth long λ (low l mode) asymmetry via beam placement: pointing, geometry change, Δλ…

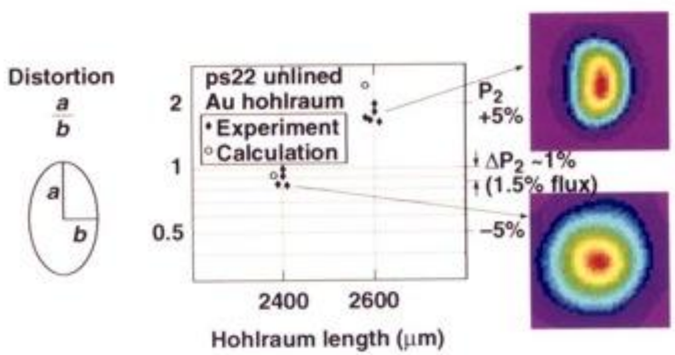
Demonstrated on Nova (which only had 1 beam angle)











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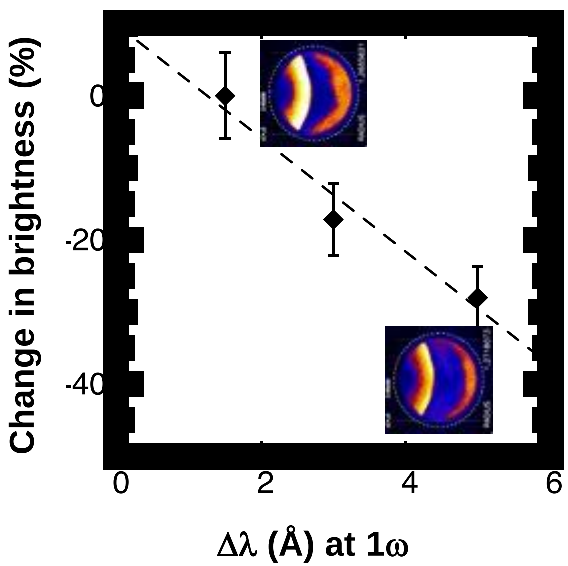
NIC has increased flexibility due to its *4 independent* beam angles

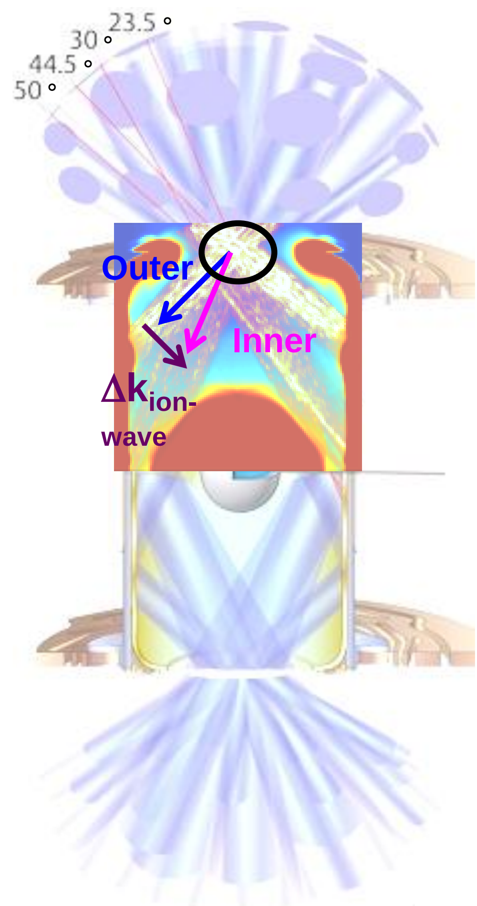
NIC Symmetry: requires a controlled energy balance between the inner and outer beams

We transfer energy from outer to inner beams via forward Brillouin scatter from ion acoustic waves, by increasing $\Delta\lambda = \lambda_{inners} - \lambda_{outers}$

Direct evidence of the effect:

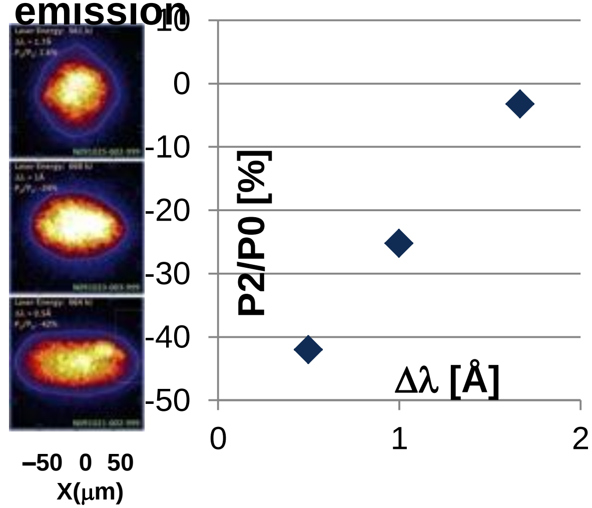
Outer beam brightness diminishes vs. $\Delta\lambda$





Indirect evidence of the effect, with very useful implications:

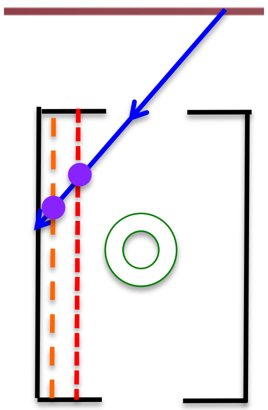
NIC '09 9 keV Capsule emission



There's a time *dependent* aspect to symmetry control

- Need symmetry to be good ***throughout*** time- not just "on average":
  — This avoids imploding target "sloshing"

- Symmetry changes in time are due to:
  — 1) Radiation albedo of wall: T and t dependent
    – Early in the pulse: symmetry is particularly sensitive to beam placements
      – But that is when we are quite flexible in energy/power choices for the various beam bundles



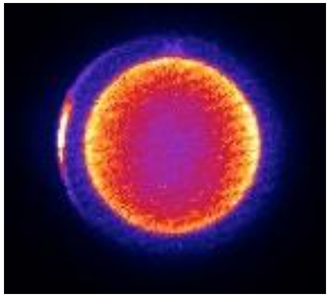
  — 2) As Au wall moves in, the beam spot moves toward the LEH
    – Use gas fill to "replace" Au with low Z gas
      – Heating this fill-gas costs some energy
      – Too much fill-gas leads to "hydro-coupling"
    – LEH closes in time

  — 3) Case/Capsule ratio changes due to imploding capsule

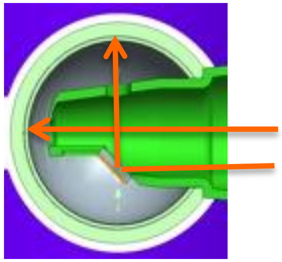
In general, we can calculate / adjust for these effects

We can measure / control time dependent symmetry

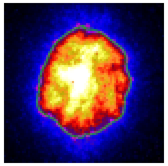
- Early in time: Re-emit balls



- Medium time:
  - — Nova: Thin shell capsule driven by truncated pulse
    - – Monitor capsule implosion image
  - — NIF: Mirrored re-entrant cone VISAR



- Late in time (main part of the pulse): Symmetry capsules
  - — Monitor capsule implosion image



NIF's multiple beams, with flexible time dependence [= beam "balance"(t)] , &/or $\Delta\lambda$, help control time dependent symmetry

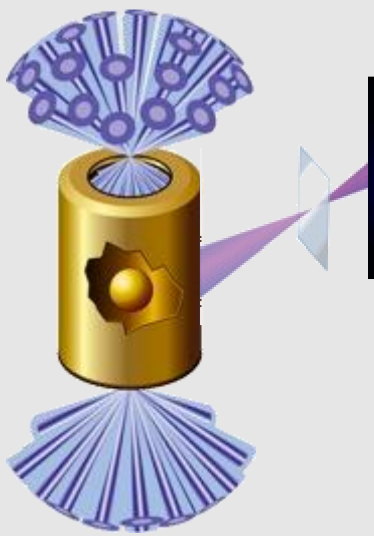
Reemit

Shape

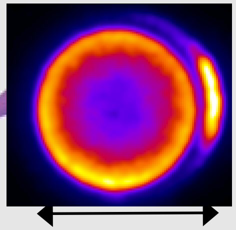
Reemit Target sets the cone power ratio for the first 2 ns to ensure symmetric foot drive

Experimental Geometry

Bi sphere "Reemit" replaces layered capsule



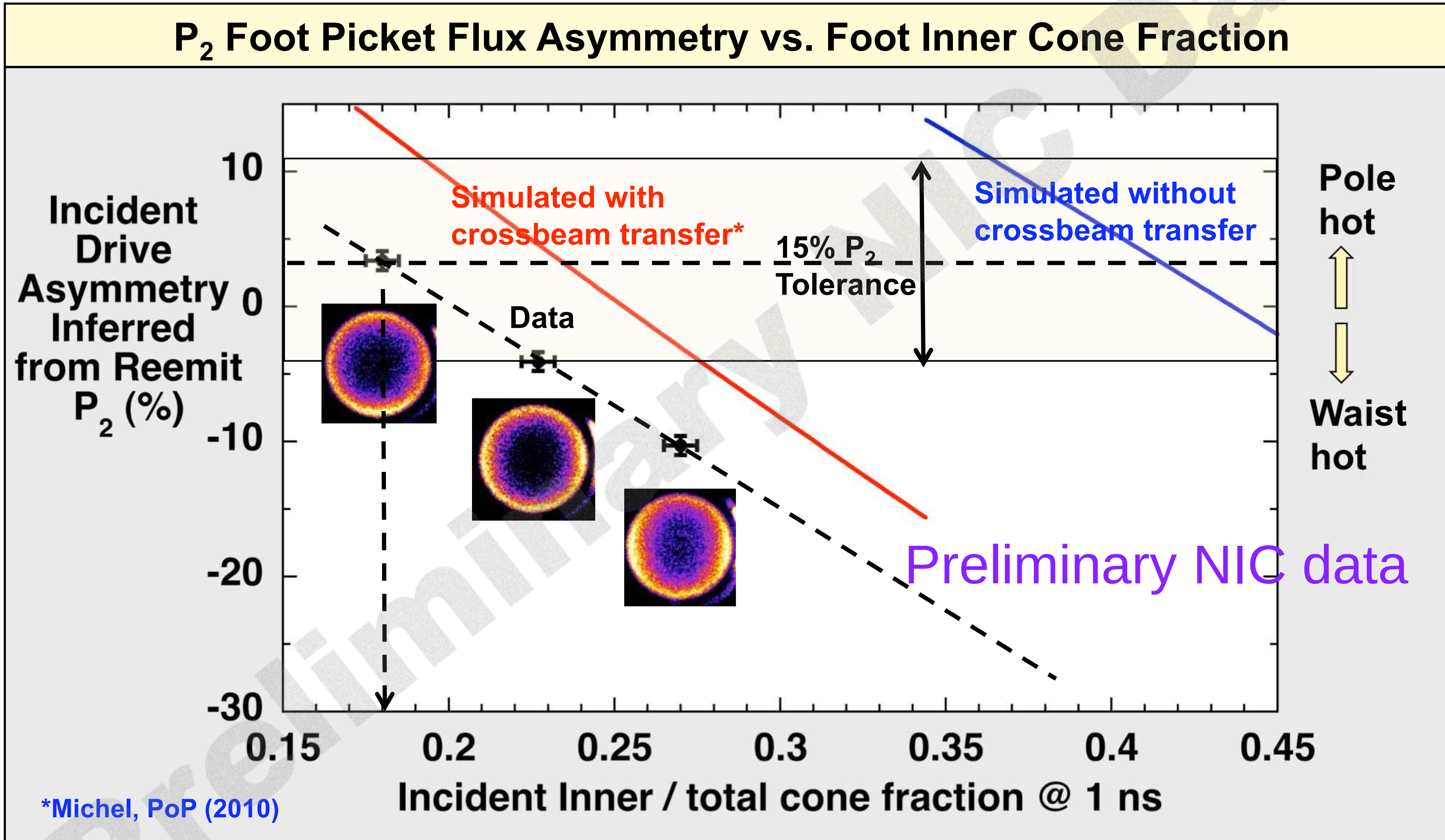
Nov. 2010
0.7 keV X-ray images



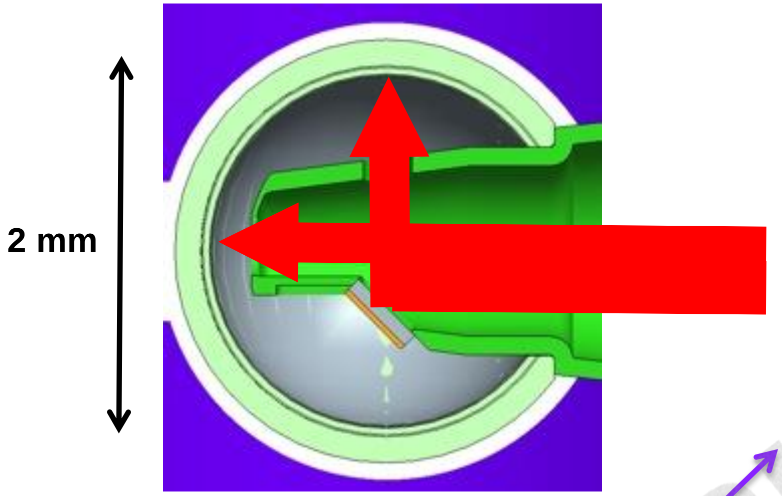
Observable:
Limb brightness vs angle

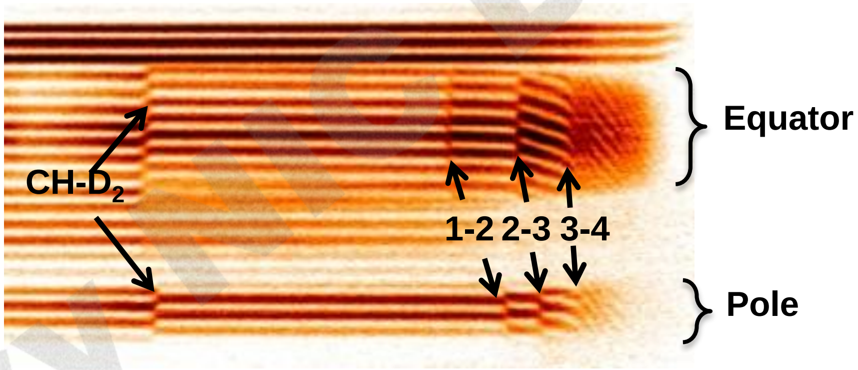
Dewald, Milovich et al RSI (2008)

Early time (1^{st} shock) drive symmetry measured to 1% and tuned



New dual axis VISAR showed 2nd and 3rd shock equator-hot, also attributable to higher crossbeam transfer





Preliminary NIC data

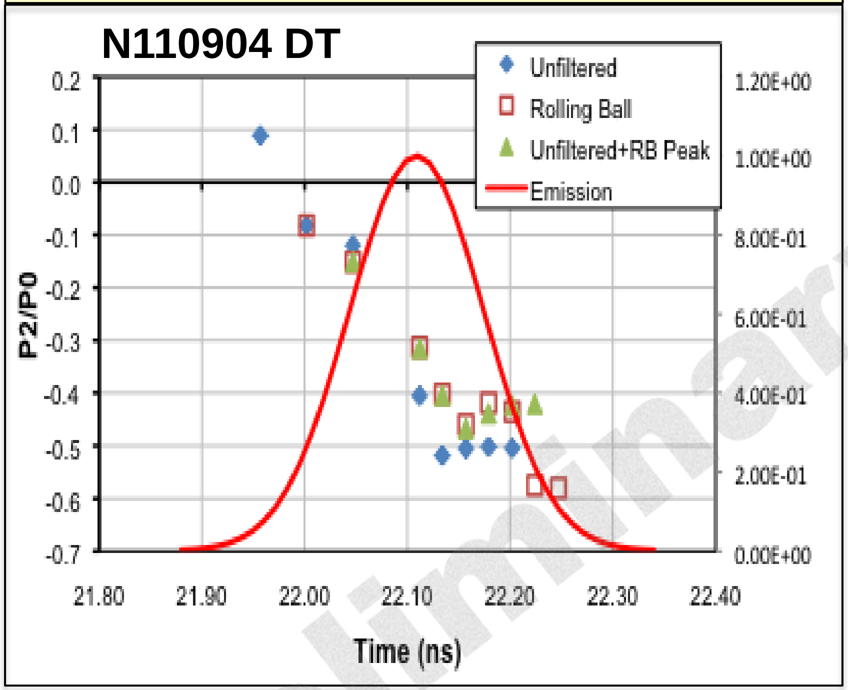
< 1% asymmetry in 1st shock velocity and breakout confirms efficacy of re-emit picket symmetry tuning

H. Robey, D. Munro, et al, 2011

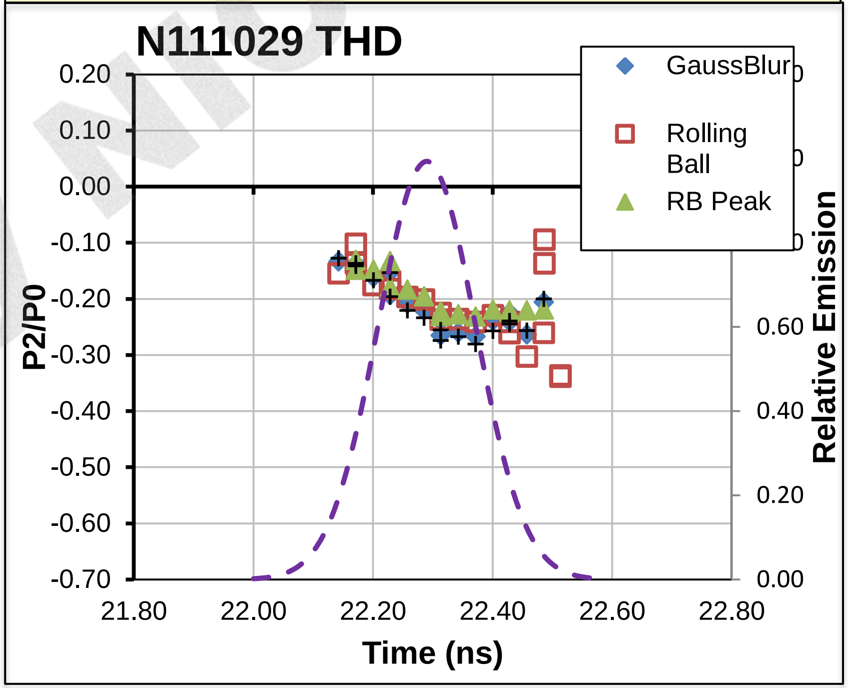
We have fixed 2nd and 3rd shock symmetry to ± 3% in velocity, ± 200 ps in merge depths by varying cone fraction and power levels

Swings in symmetry have been reduced since 2nd and 3rd cone fraction tuning

Before 2nd and 3rd cone fraction tuning



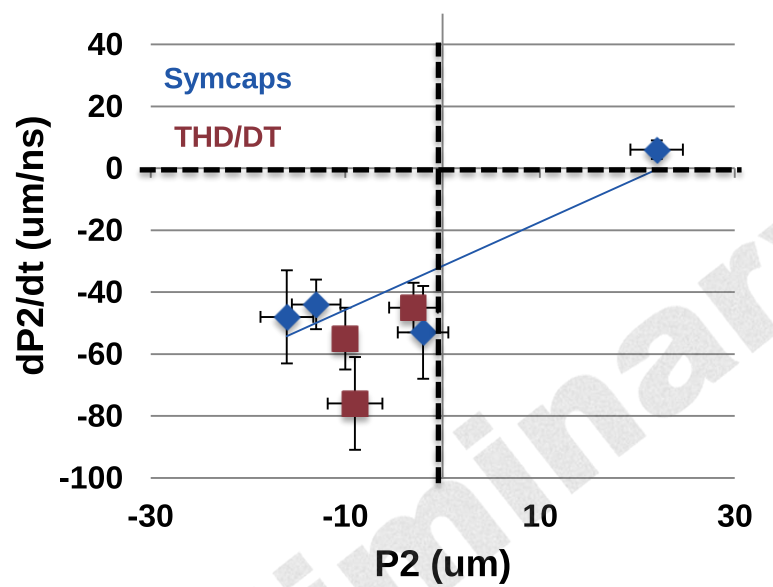
After 2nd and 3rd cone fraction tuning



D. Callahan et al PoP **19**, 056305 (2012)

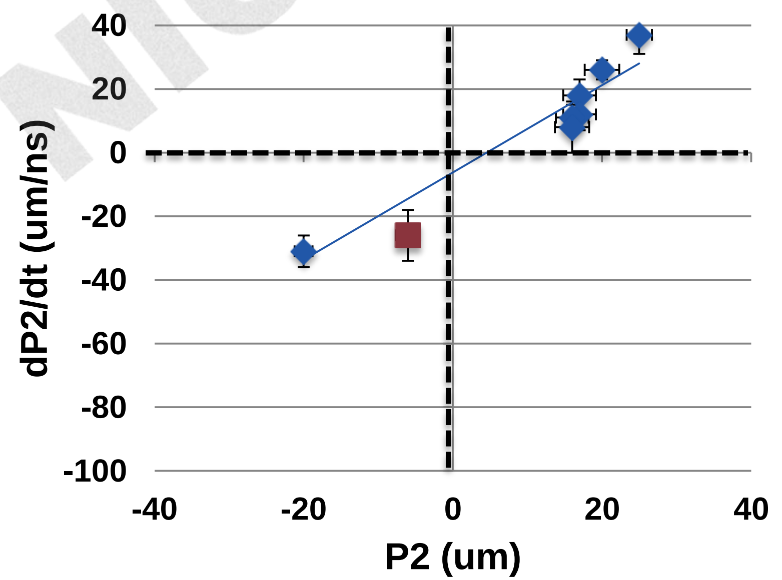
Implosions with symmetric shocks tend towards pure radial compression

Before **2nd and 3rd cone fraction tuning**



dP2/dt negative when P2=0

After **2nd and 3rd cone fraction tuning**

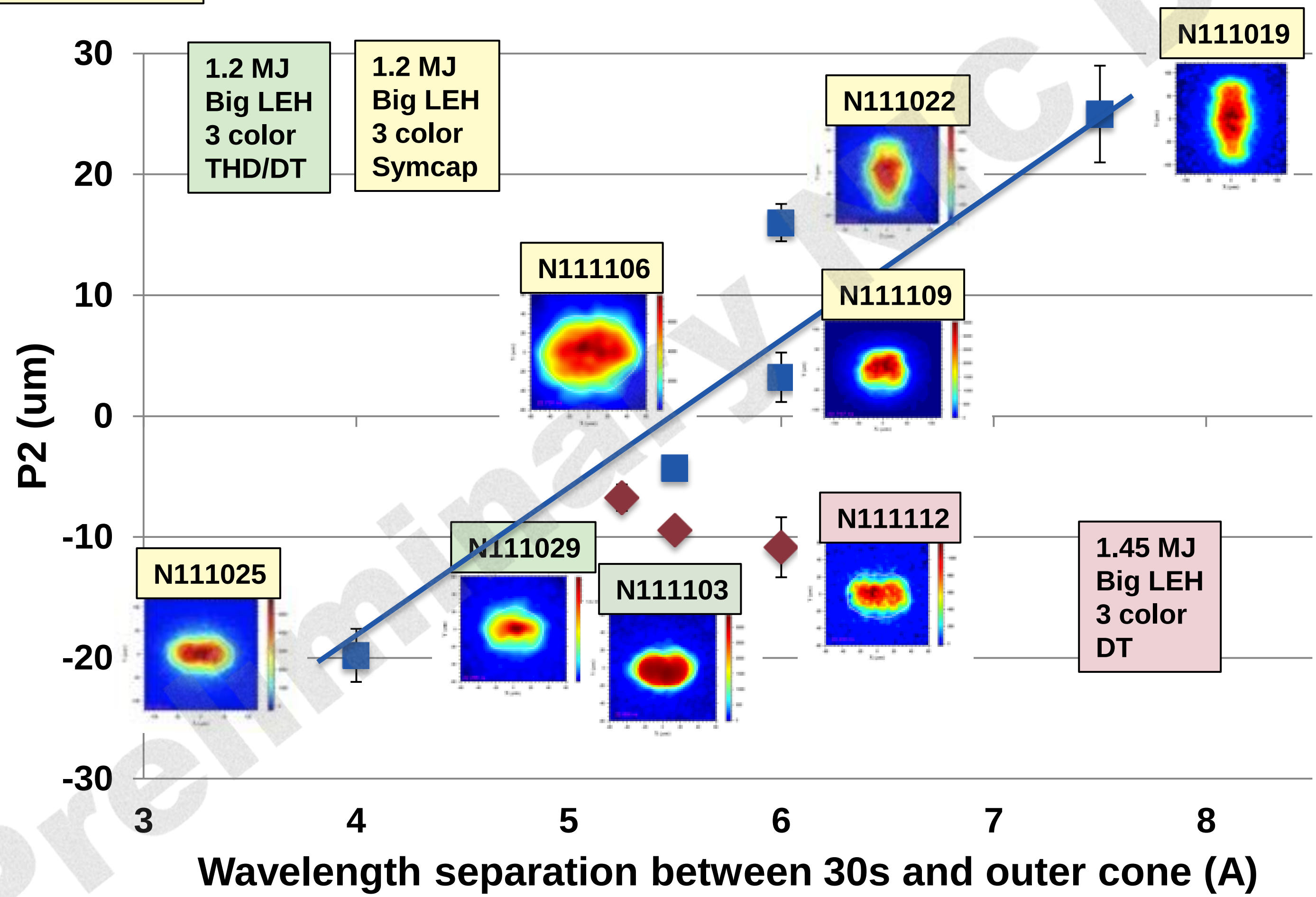


dP2/dt small when P2=0

With pure radial compression, swing in P2 should be small when P2 is small

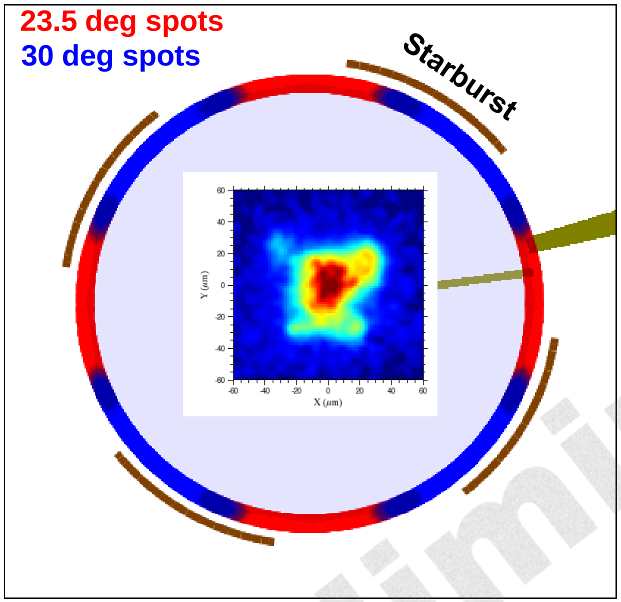
We have mapped out the P2 tuning curve for two color tuning

575 hohlraums



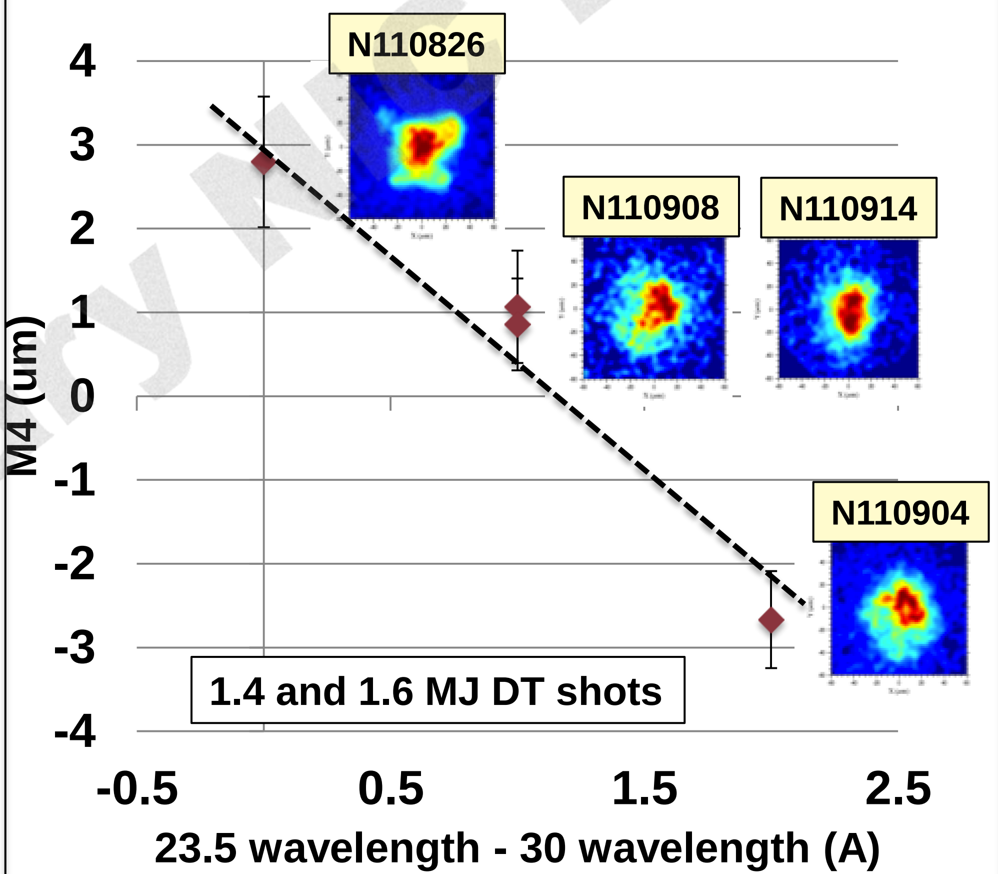
The polar M=4 symmetry can be improved using three color tuning

Increasing separation between 23.5 and 30 beams puts more power on 23.5 beams



Calculations show reversal – image is larger where we are pushing too hard

Experimental tuning curve for M=4



To be reasonably close to expectations, and be in a tuning regime, we'd like to know the plasma conditions:

We'd like to know the hohlraum's n, v, T_e, T_R, Z, I_L vs. space and time

- **For Laser Plasma Interactions (LPI)**
- **For beam propagation & symmetry**

Modeling challenges include:

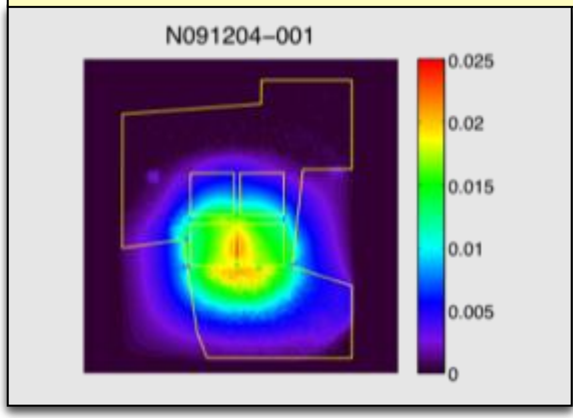
The <u>long pulse</u> laser propagating through:

- **The high Z walls moving into the <u>large</u> gas filled hohlraum**
- **Ablator dynamics that contribute to the hohlraum plasma**
- **The evolving laser entrance hole (LEH)**
- **Non-LTE high Z atomic physics**
- **Non-local electron transport**
- **Hot electrons production and transport**

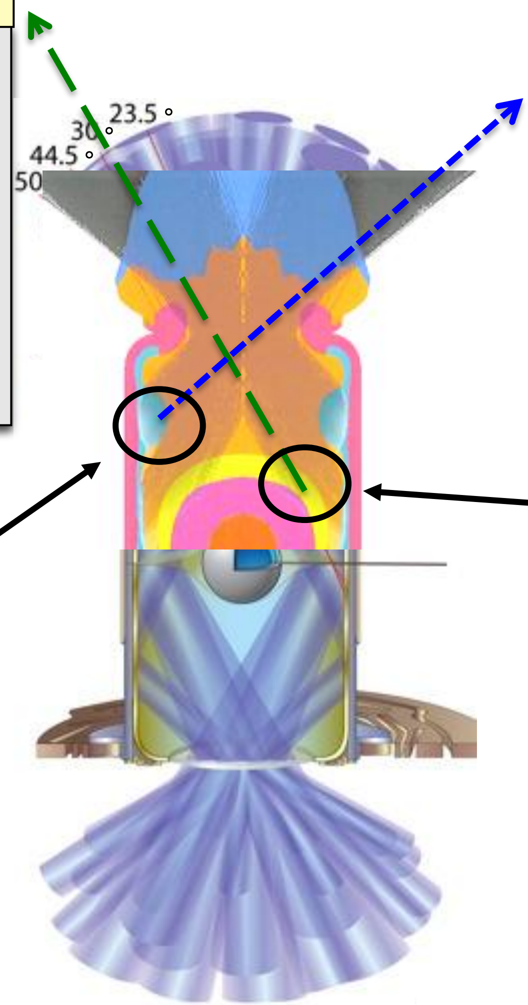
Then comes the LPI issues in that <u>large</u> plasma medium…

Coupling: Stimulated scatter within the hohlraum can lead to energy loss: incoming laser reflects back out

Coupling: LPI must be low enough, so that enough energy is available for drive



See the following talk by D. Hinkel

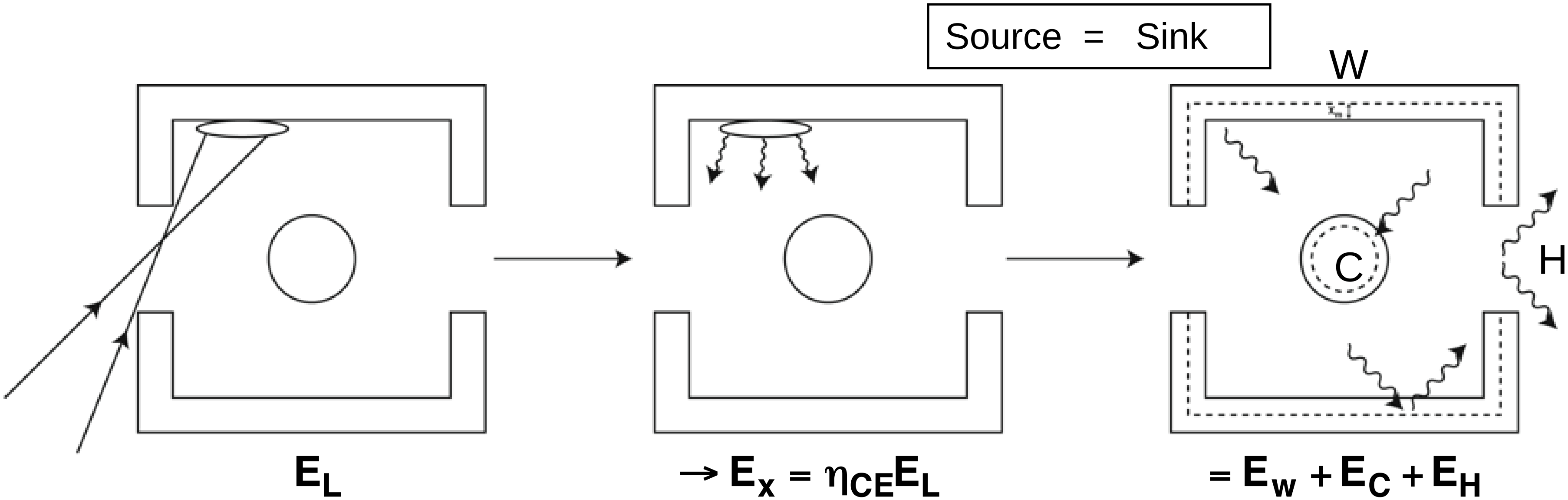


SRS of inner cone beams in fill-gas & ablator blow-off: Laser reflects off of electron plasma wave

SBS of outer cone beams in "gold bubble": Laser reflects off of ion wave

Besides reflecting the incident power, that plasma wave also makes hot electrons

A chalkboard talk on hohlraum scaling

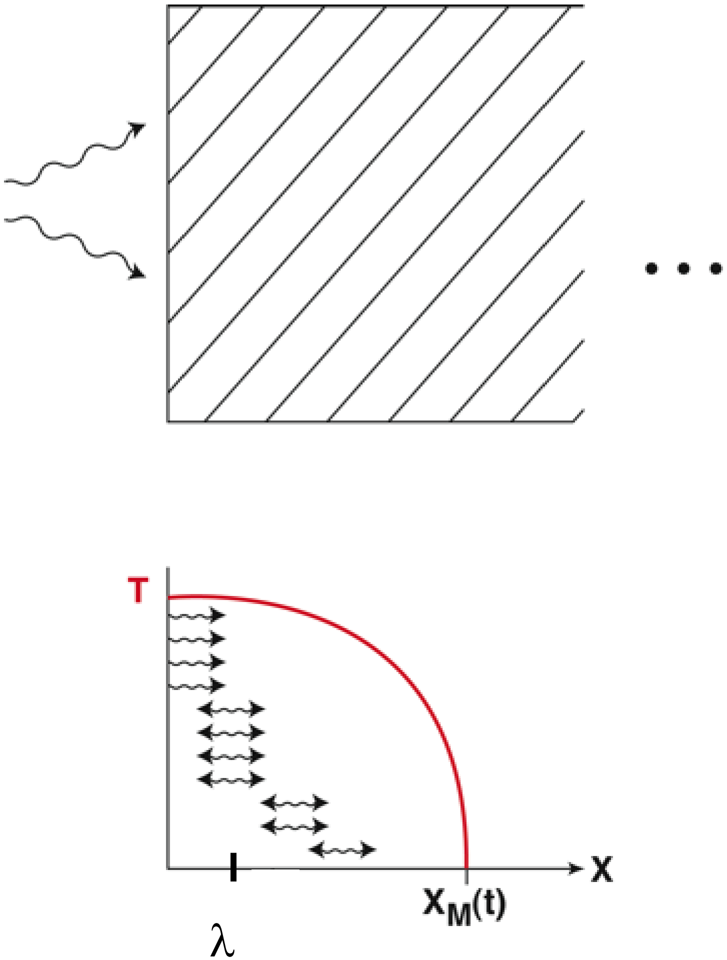


$E_W = e_{th} \bullet M_{hW}$

$= e_{th} \bullet \rho \bullet x_M \bullet A$

Find $x_M\,(t, T, \kappa, \ldots)$

Radiation diffusing into the wall via a random walk results in a non-linear heat ("Marshak") wave



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The Marshak depth made easy

$$\frac{d}{dt}(energy\ density) = \frac{-d}{dx}(diffusive\ energy\ flux)$$

$$\frac{d}{dt}\left(\rho e_{th} + \cancel{aT^4}\right) = -\frac{d}{dx}\left(\frac{c\lambda_R}{3}\frac{d}{dx}\left(aT^4\right) + \cancel{\frac{V_e\lambda_e}{3}}\frac{d}{dx}\left(\rho e_{th}\right)\right)$$

$$\frac{\rho e}{t} \sim \frac{1}{x}\lambda\frac{caT^4}{x} \sim \frac{1}{x}\frac{1}{\kappa\rho}\frac{\sigma T^4}{x} \qquad \text{so: } m_F^2 \equiv (\rho x_F)^2 \sim \frac{\sigma T^4 \bullet t}{\kappa \bullet e}$$

κ = Opacity

e = Specific heat

Using power law fits for opacity (κ) and specific heat (e), get expression for wall loss (E_w)

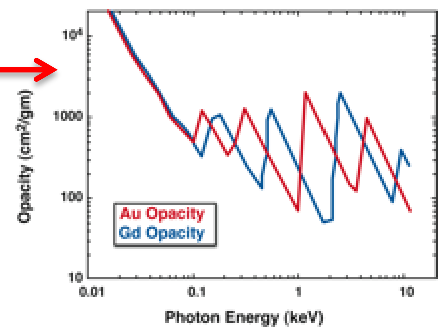
$$m_F \equiv \rho X_F \sim \sqrt{\frac{\sigma T^4 \bullet t}{\kappa \bullet e}} \quad + \quad \text{Au EOS}: \quad \left.\begin{array}{l} \kappa = \kappa_o \rho^{0.2} / T^{1.5} \\ e = e_o T^{1.6} / \rho^{0.14} \end{array}\right\}$$

$$\text{Þ} \; m_F \sim \frac{T^{1.91} t^{.52}}{(k_o e_o)^{0.48}} \; \text{Þ} \quad \frac{E_w}{A_w} \sim e m_F \sim \frac{e_0^{\;0.7}}{k_o^{\;0.4}} T^{3.34} t^{.6}$$

To reduce wall loss (vs. pure Au):

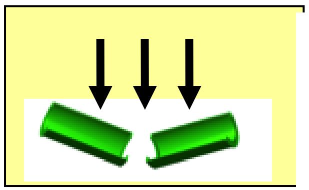
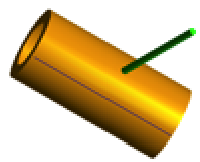
Decrease e_o ~$(Z_B+1)/A_N$, so use higher A_N, e.g. U

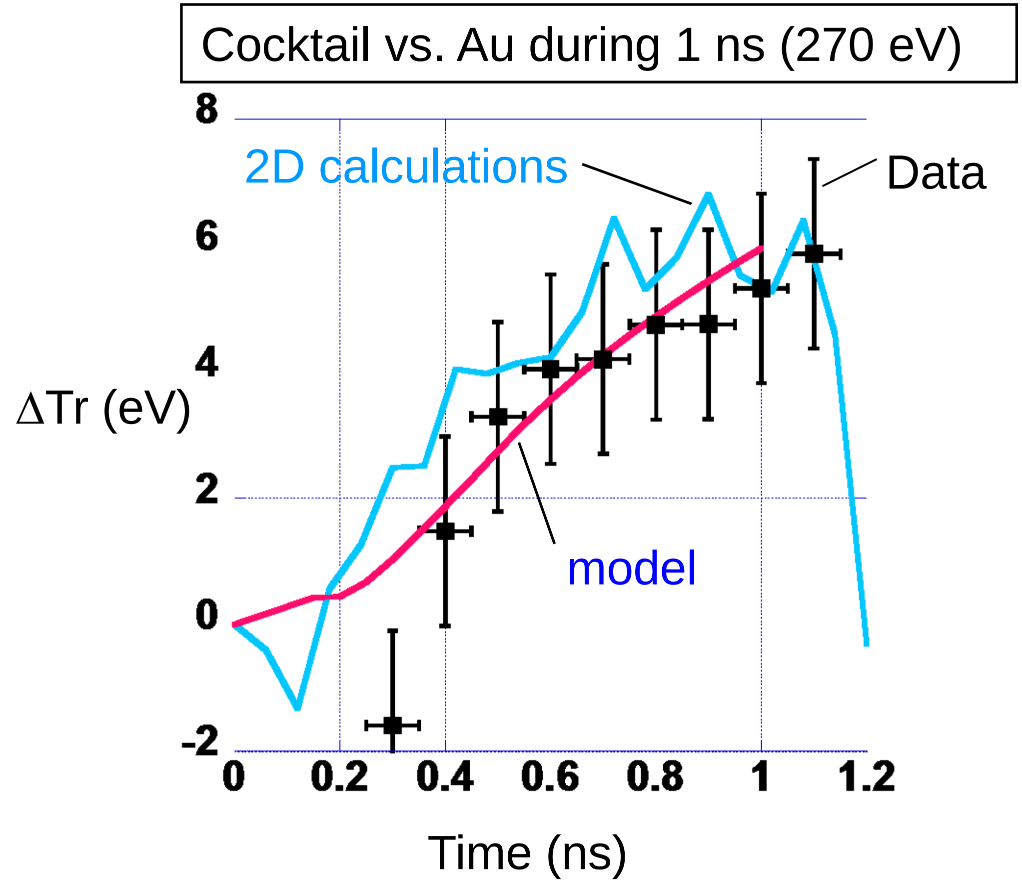
Increase κ_o via a cocktail mixture of elements



e_o & κ_o are scale *size* *independent*

Omega experiments proved the principle



<u>The "Canoe" Approach;</u>

- 60% U(Nb), 20% Au, 20% Dy Mixture sputtered onto inside of split gold hohlraum, then "sealed" with an Au overcoat, which is then glued together like 2 canoes.

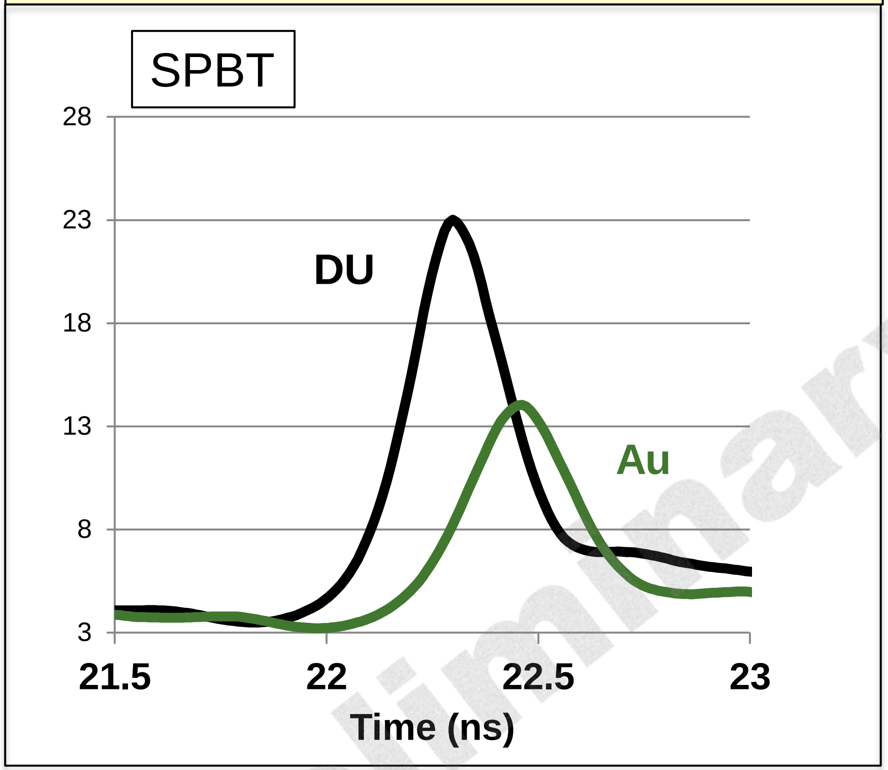
- These steps prevent oxidation

- Schein, Jones, Rosen et al PRL 98, 175003 (2007)

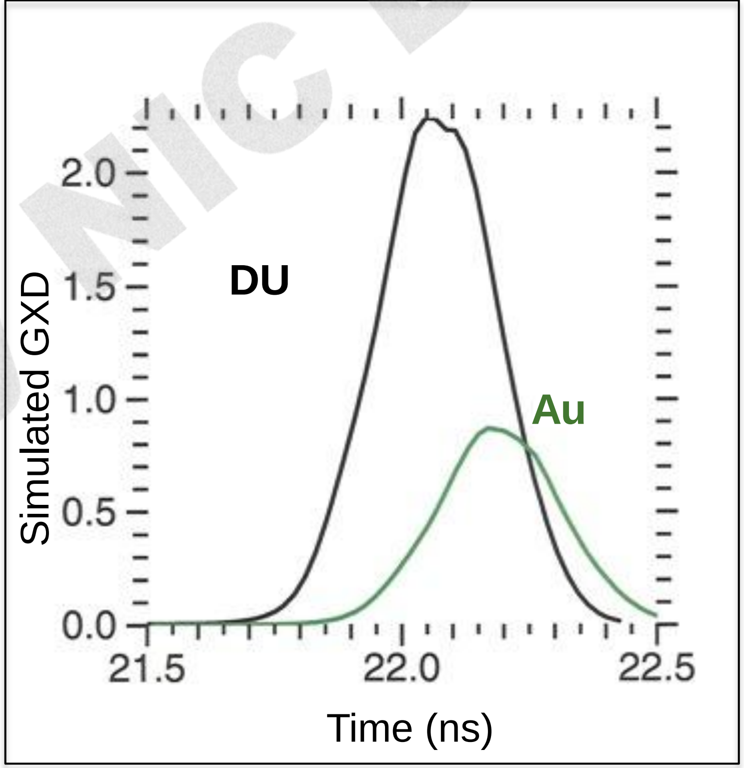
U shares part of the same advantages (& issues like O !) as UAuDy, and its success at NIF was no surprise

Depleted uranium hohlraum showed 160 ps earlier bangtime than Au hohlraum

DU shows 160 +/- 37 ps earlier bangtime



Simulation 120 ps earlier

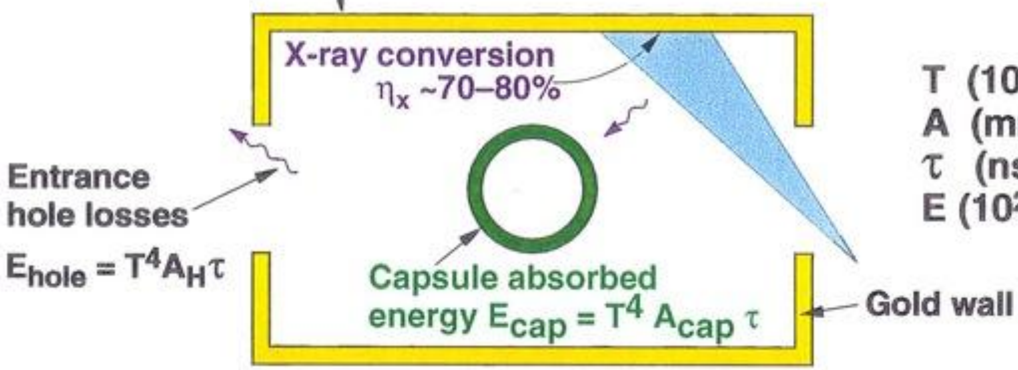


Capsules were carefully selected to have same dimensions to ensure good comparison
Delivered laser energy in peak for uranium shot was 99.4% of energy in gold shot

Simple model estimate of hohlraum coupling efficiency

Wall Loss coefficient of ~ 0.5
(Hammer & Rosen PoP **10**, 1829 92003)

$$E_W \sim A_W X_M T \approx 0.5\, A_W T^3 \sqrt{\tau} / \sqrt{K_0}$$



T (10^2 eV)
A (mm)
τ (ns)
E (10^2 J)

$$\frac{E_{cap}}{E_{driver}} = \eta_{x\text{-ray}} \left(\frac{E_{cap}}{E_{cap} + E_{hole} + E_{wall}} \right) = \frac{\eta_{x\text{-ray}}}{1 + a_h + a_w / \bar{N}_w}$$

~0.06 Nova
~0.11 NIF
~0.18 HiY

$$a_h \approx 2 \quad a_w \approx \left(\frac{R_{Wall}}{R_{cap}} \right)^2 \approx \left(\frac{4R_o}{\frac{3}{4}R_o} \right)^2 \approx 30 \qquad \bar{N}_W = 2\,T \sqrt{\tau} \sqrt{K_0}$$

~4 Nova
~8 NIF
~14 HiY

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01JDL/pdd

12/3/98
MDR/mcm

Summary of the basic issues / trade-offs of parts 1 & 2

Symmetry & Coupling have conflicting trade-offs

Symmetry would like:

1) **Large case to capsule ratio**
2) **Large amount of volumetric low Z gas fill**

Coupling would like the opposite !

Capsule physics has a similar set of conflicting trade-offs

Hydro-stability would like:

Low aspect ratio (thick ablator)

But to get to TN velocity need high P, thus high drive (I_L, T_r)

LPI-stability would like the opposite !

<u>Capsule ablator choice impacts all of the above issues / trade-offs</u>


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